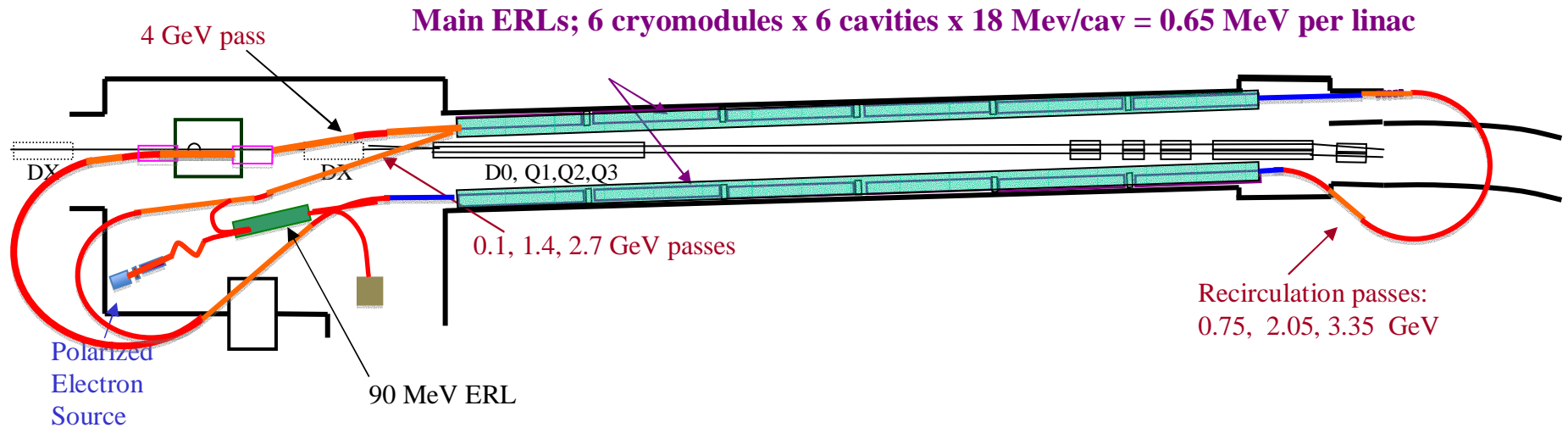# Progress on MeRHIC Design

J.Beebe-Wang, I.Ben-Zvi, A.Burrill, R.Calaga, X.Chang,
A.Fedotov, H.Hahn, Y.Hao, L.Hammons, D.Kayran,
P.Kovach, V.N.Litvinenko, G.Mahler, C.Montag, B.Parker,
S.Plate, E.Pozdeyev, V.Ptitsyn, T.Roser, S.Tepikian,
J.Touzzolo, D.Trbojevic, N.Tsoupas, G.Wang

MeRHIC at IR2 region

Main ERLs; 6 cryomodules x 6 cavities x 18 Mev/cav = 0.65 MeV per linac

4 GeV pass

DX

DX

D0, Q1,Q2,Q3

0.1, 1.4, 2.7 GeV passes

Recirculation passes:
0.75, 2.05, 3.35 GeV

Polarized
Electron
Source

90 MeV ERL

IR2 region:

- asymmetric detector hall is very appropriate for asymmetric detector for e-p collisions
- long wide (7.3m) tunnel on one side from the IR is good to place the ERLs

Detector hall accommodates also the injector system (polarized gun, bunching system, pre-accelerator ERL) and the beam dump.

Recirculation passes are going outside of the existing tunnel: warm magnets, acceptable synchrotron radiation power.

MeRHIC parameters for e-p collisions

	not cooled		pre-cooled		high energy cooling	
	p	e	p	e	p	e
Energy, GeV	250	4	250	4	250	4
Number of bunches	111		111		111	
Bunch intensity, 10^{11}	2.0	0.31	2.0	0.31	2.0	0.31
Bunch charge, nC	32	5	32	5	32	5
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	6	29	1.5	7.3
rms emittance, nm	9.4	9.4	3.8	3.8	0.94	0.94
beta*, cm	50	50	50	50	50	50
rms bunch length, cm	20	0.2	20	0.2	5	0.2
beam-beam for p /disruption for e	1.5e-3	3.1	3.8e-3	7.7	0.015	7.7
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	0.93		2.3		9.3	

SRF Linac

I. Ben-Zvi, A.Burrill, R.Calaga, H.Hahn, L.Hammons, S.Plate, E.Pozdeyev …

The ERLs will use 703 MHz superconducting RF cavities
for the acceleration and the energy recovery.
State-of-the-art cavity design for high current beam operation.

Recently: successful cooldown of a test cavity (ERL Test Facility)
first measurements of EM modes.

36 cavities per linac. Design of individual crymodule,
incorporating 6 SRF cavities is under development.

The challenge: to make the design
(fundamental couplers, HOM dampers, tuners ..)
as compact as possible, to fit the existing
straight section of the tunnel.
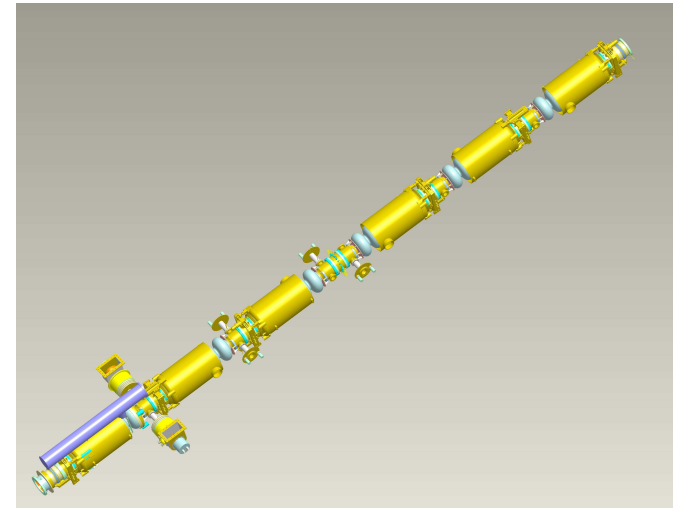
# Recirculation Passes and IR Lattice Design

Lattice requirements/issues:

-asynchronous recirculation passes ($M_{56}=0$)

-control of path length and M_{56} parameter

-minimize the dispersion function

-warm dipole and the quadrupole magnets
-merging/splitting beams in different recirculation passes with proper matching
to the linacs

-managing the synchrotron radiation through detector region

-integration of the accelerator and detector design (detector magnets ...)

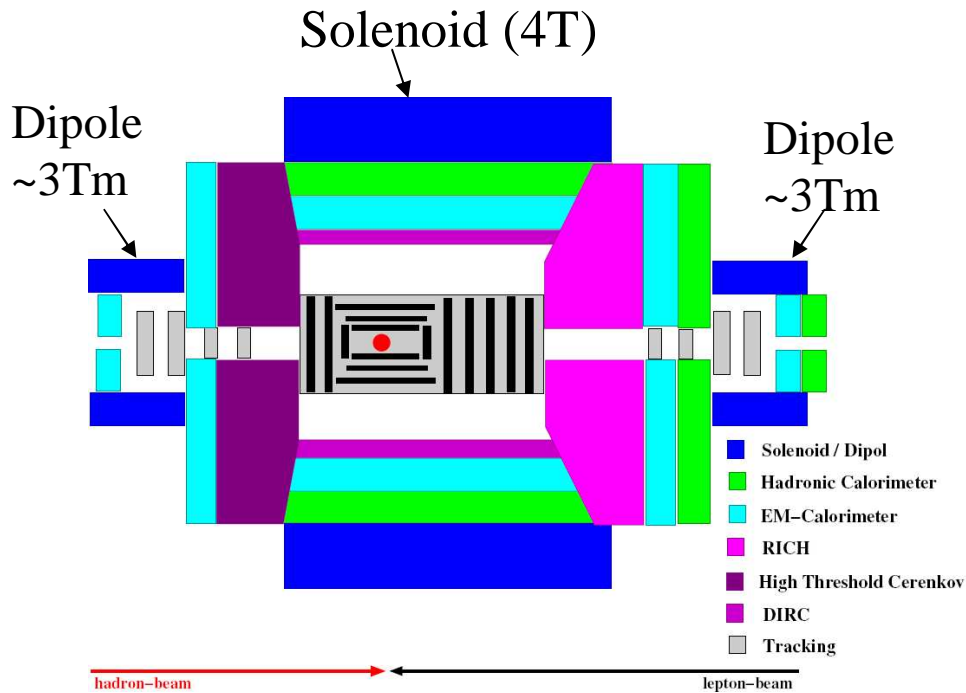-low energy transport optics for high momenum spread beam

Lattice design development:
D.Trbojevic, D.Kayran, C.Montag, B.Parker, S.Tepikian,N.Tsoupas

# Example of recirculation pass optics (for 3.35 GeV pass)
D.Kayran, D.Trbojevic
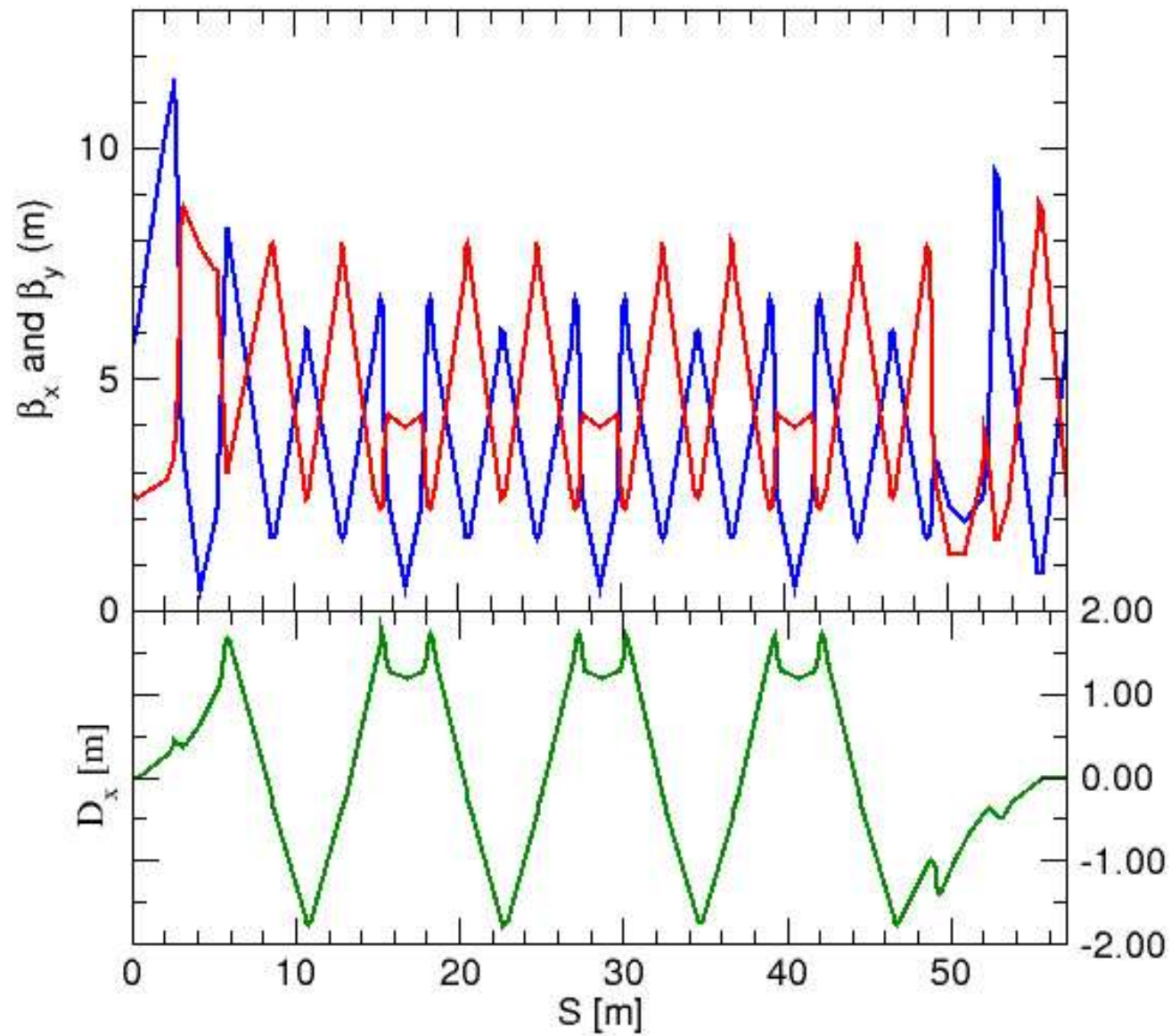
Accelerator and detector integration and SR protection

J.Beebe-Wang, C.Montag, B.Parker, D.Trbojevic

Solenoid (4T)

Dipole ~3Tm

Dipole ~3Tm

Solenoid / Dipol
Hadronic Calorimeter
EM–Calorimeter
RICH
High Threshold Cerenkov
DIRC
Tracking

hadron–beam

lepton–beam

To provide effective SR protection:
-soft bend (~0.05T) is used for final bending of electron beam
-combination of vertical and horizontal bends
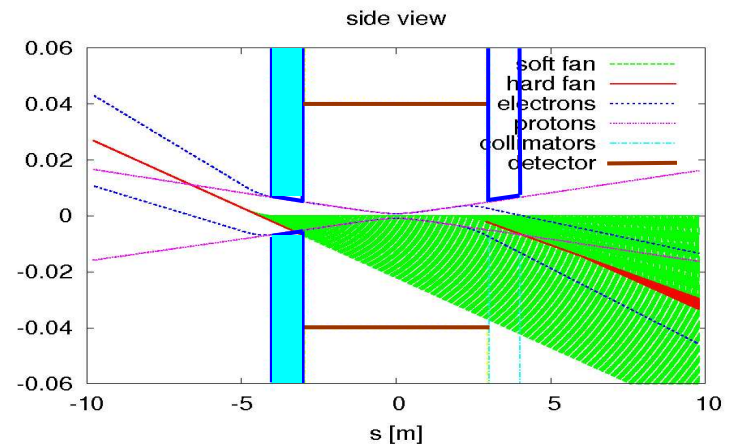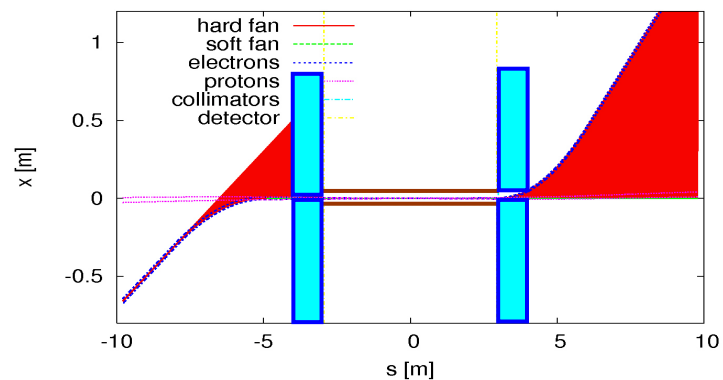
Beam Dynamics Studies

E.Pozdeyev, A.Fedotov, Y.Hao, G.Wang

Main factors affecting the beam dynamics have been evaluated:

-Beam-beam interactions, including kink instability (protons) and electron beam disruption
-BBU instability
-Energy losses due to cavity wakes
-Toushek and Beam-gas scattering
-Coherent Synchrotron Radiation (possible experiment at ATF)

Beam energy losses

E.Pozdeyev

Energy losses happen due to:

Wakefield losses-> mainly in linac cavities

Synchrotron radiation emission -> in dipoles of the recirculation passes

As results: average beam energy loss and momentum spread increase.

Wakes in Linac (ABCI simulations) 0.54 MV/linac.
Total energy loss to SR and wakes: 15.3 MeV.
Total power loss 765 kW.
Energy diff. at 750 MeV is 2%.

Best compensation scheme includes additional cavities:
two 2nd harmonic RF cavities (0.7 MV,210 kW)
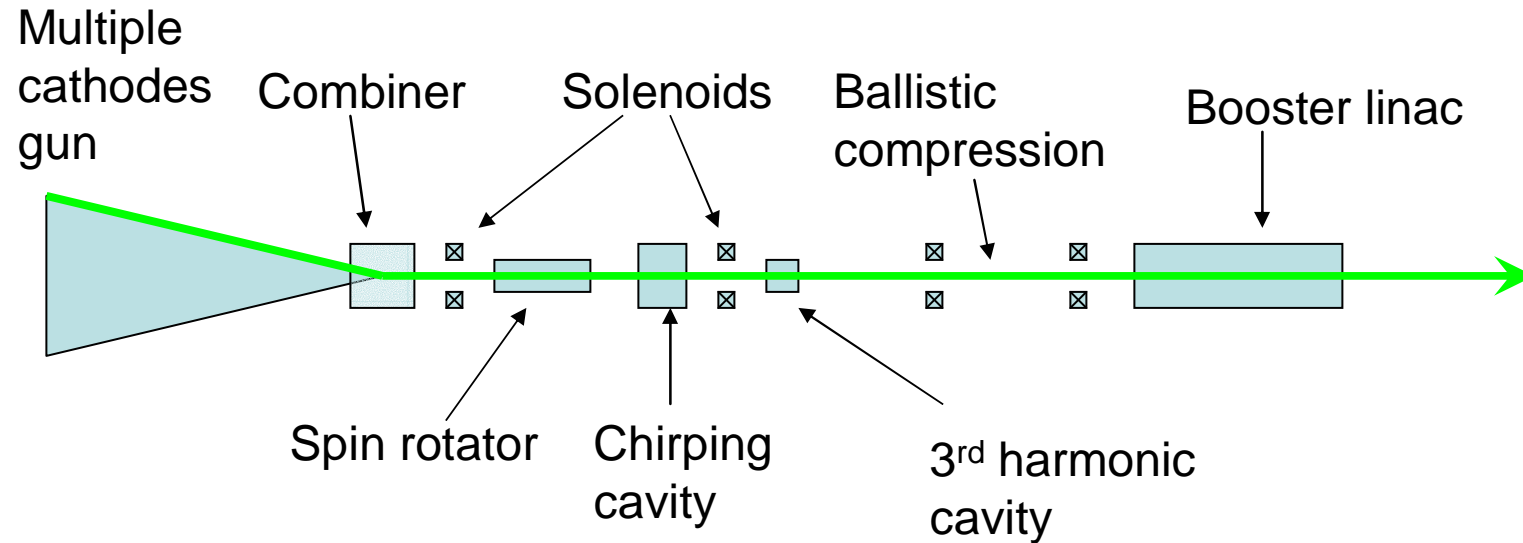one 1st harmonic cavity (6.5 MV, 325 kW)
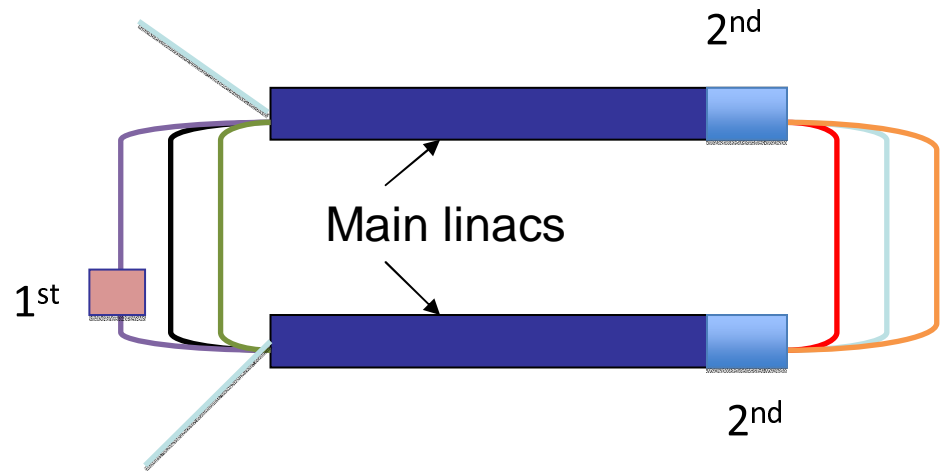
With the compensation the energy difference between accelerated and decelerated beam in any pass: $\Delta E < 0.06\%$

Energy spread after deceleration (at 100 MeV) ~10%.

Injector layout

X.Chang

Multiple cathodes gun

Combiner

Solenoids

Ballistic compression

Booster linac

Spin rotator

Chirping cavity

3rd harmonic cavity

Voltage: 200kV

Laser parameters: transverse uniform with R_{MAX}=4mm
longitudinal Gaussian with σ_L=250ps (FWHM=500ps)
Bunch charge = 5nC/bunch
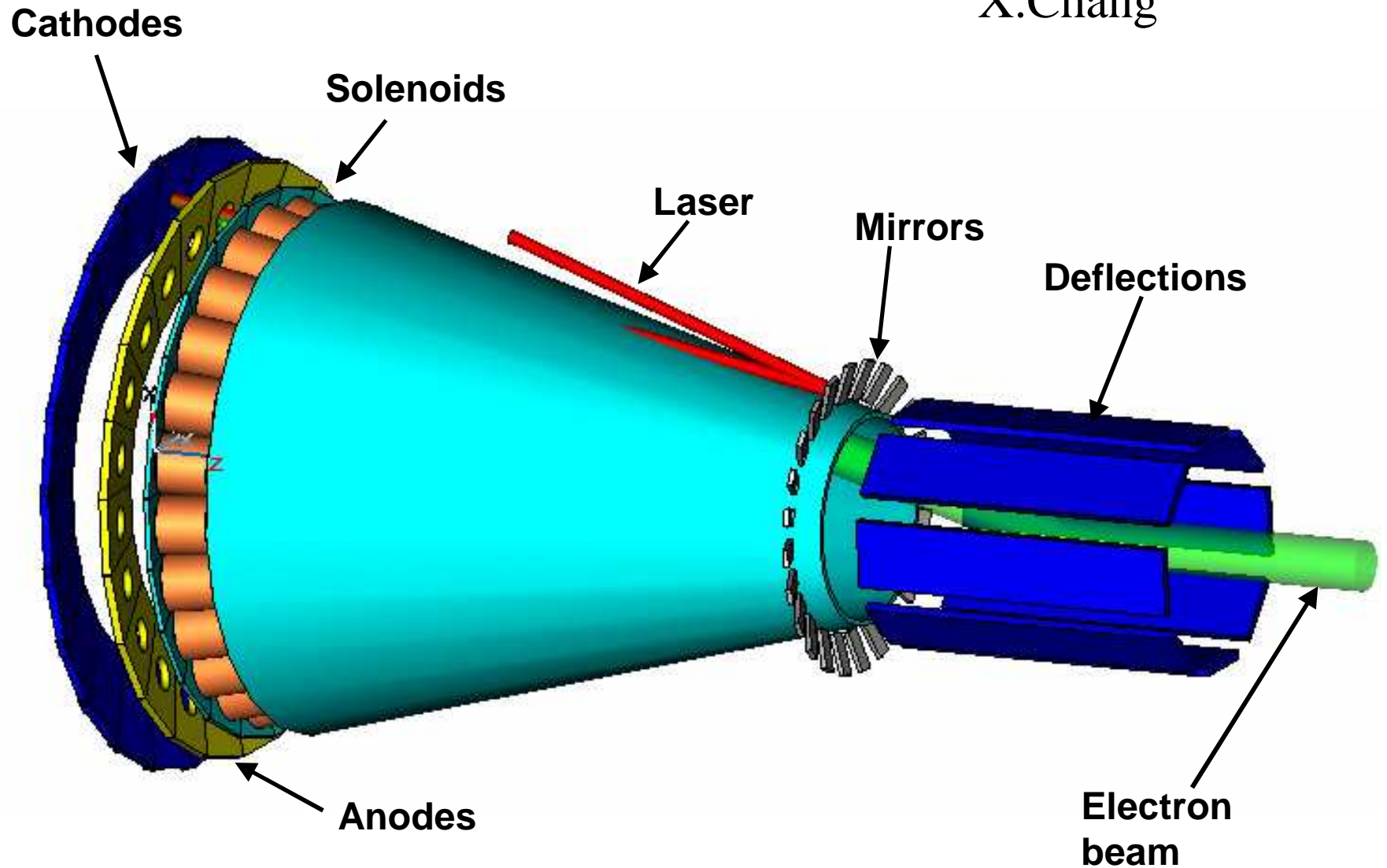
Chirping cavity & Booster linac frequency: 112MHz

Energy after booster linac: 10MeV

rms dE/E at exit: 1%

Gatling gun

X.Chang

Cathodes

Solenoids

Laser

Mirrors

Deflections

Anodes

Electron beam

Polarization Control

- Protons:

   helical spin rotators, similar to those used in present experiments at IR6 and IR8.

- Electrons:

  – Rotation around horizontal axis: Wien Filter type spin rotator at 200 kV

  – Rotation around vertical axis: by synchronous small readjustments of energy gains in main linacs.

  – Combination of those rotation will provide wanted polarization orientation at the IP.

 – For longitudinal polarization: ~0.1 rad spread of spin directions due to momentum spread.

Summary:

- Intensive design development of medium energy electron-ion collider is underway.

- Lattice design of all major machine component has been done:
    - Main linacs
    - Recirculation passes
    - Interaction region

- Main factors affecting the beam dynamics have been evaluated.

- Design development of high current polarized source, based on multiple cathods is underway.

- Design development continues for the linac cryomodule.

The work accent is shifting now to the technical design of accelerator hardware (magnets, vacuum chamber, cryomodule) and to the evaluation of effects of machine imperfection/errors on the beam.
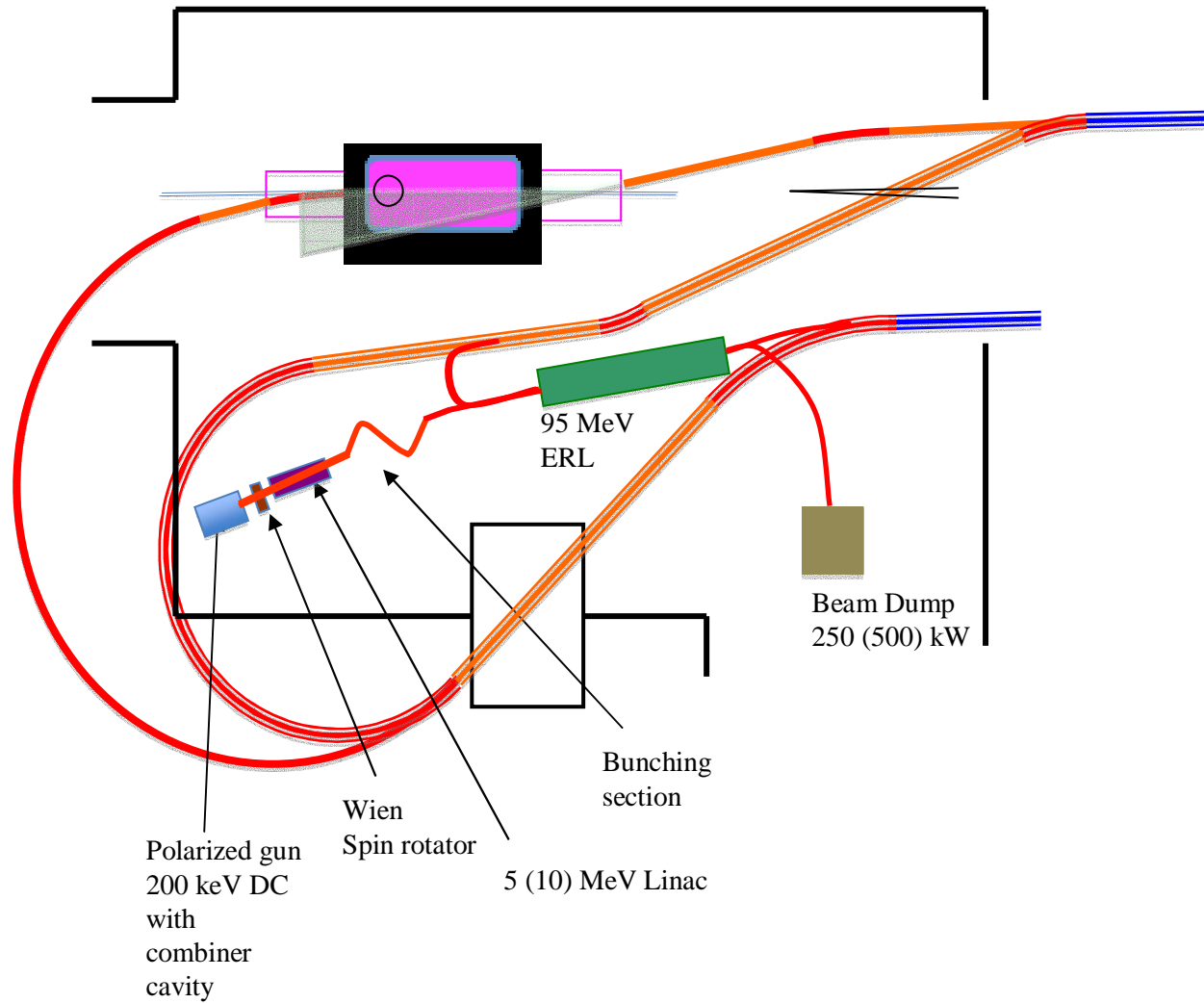
Backup slides

RHIC and MeRHIC
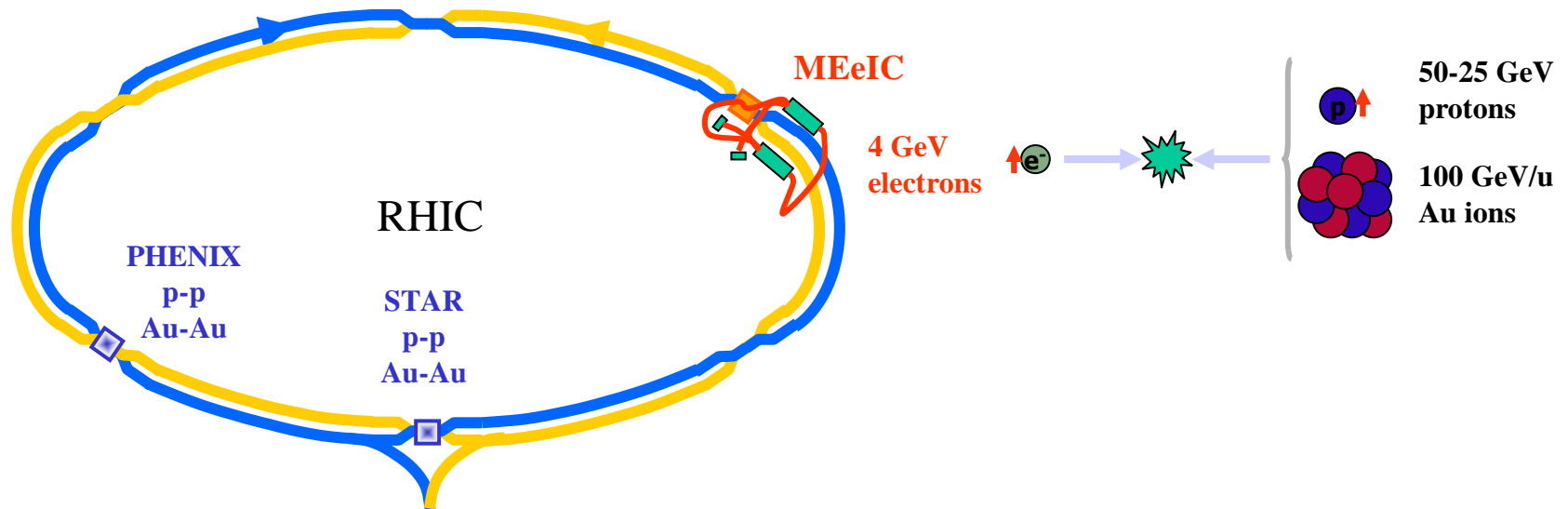
- ➤ MEeIC – Medium Energy electron-Ion Collider.
- ➤ Takes advantage of the existing RHIC machine. Electrons collide with protons and ions from RHIC Blue ring.
- ➤ Electron-proton, electron-heavy ion collisions in IR2 RHIC region with up to 63 GeV center-of-mass energy.
- ➤ Polarized electron and proton beams. Longitudinal polarization orientation at the collision point for both beams.
- ➤ Parallel operation with the p-p (or ion-ion) collisions at PHENIX and STAR detectors.
- ➤ Electron accelerator is based on energy-recovery linacs.

IR2 Hall : Detector and Injector System

95 MeV
ERL

Beam Dump
250 (500) kW

Bunching
section

Wien
Spin rotator

Polarized gun
200 keV DC
with
combiner
cavity

5 (10) MeV Linac

Machine luminosity

Limiting factors:

- Maximum average electron current as allowed by the polarized source, SR losses, BBU.
- Electron charge/bunch (or peak current): wakes
- Electron beam disruption
- Minimum collision beam size: proton beta* is limited by existing RHIC triplets.
- Maximum proton current: electron cloud, beam-beam from p-p collision points .

Main design line: no cooling assumed for the proton beam.

Upgrade options (with higher luminosity):
-pre-cooling (e-cooling) at the injection energy (like in eRHIC)
-cooling at high (store) energy (CEC). No parallel p-p operation possible.
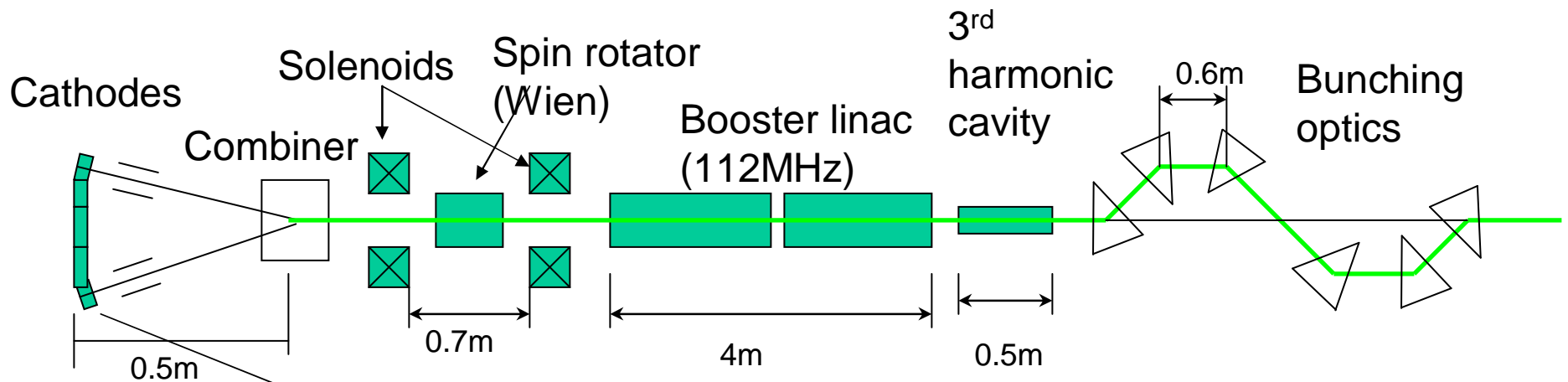
Proton and ion beam for MeRHIC

- Goal: modifications for proton beam should be minimal

- IR design: existing triplets, removal of IR2 DX magnets

- Also will take advantages of planned improvements in RHIC (for RHIC operation): 56 MHz SRF, stochastic cooling (for ions) …

Proton beam parmeters

	For MeRHIC	Presently achieved
Energy, GeV	250	**Several runs at 100 GeV. First 250 GeV run is underway**
Number of bunches	111	111
Bunch intensity, 10^{11}	2.0	**1.7 (at 100 GeV)**
Normalized 95% emittance, 1e-6 m	15	**<10 mm*mrad at the injection ~18 mm*mrad at the store on average in previous runs**
beta*, cm	50	70
rms bunch length, cm	20	**50 cm with 28 MHz system In future, shorter bunches with combination of 9 MHz RF (ramp) + 56 MHz SRF (store)**
Polarization, %	70	**60 (at 100 GeV)**

Injector configuration

X. Chang

Cathodes
Solenoids
Spin rotator (Wien)
Combiner
Booster linac (112MHz)
3rd harmonic cavity
0.6m
Bunching optics

0.5m
0.7m
4m
0.5m

200 kV DC gun
with multiple cathodes
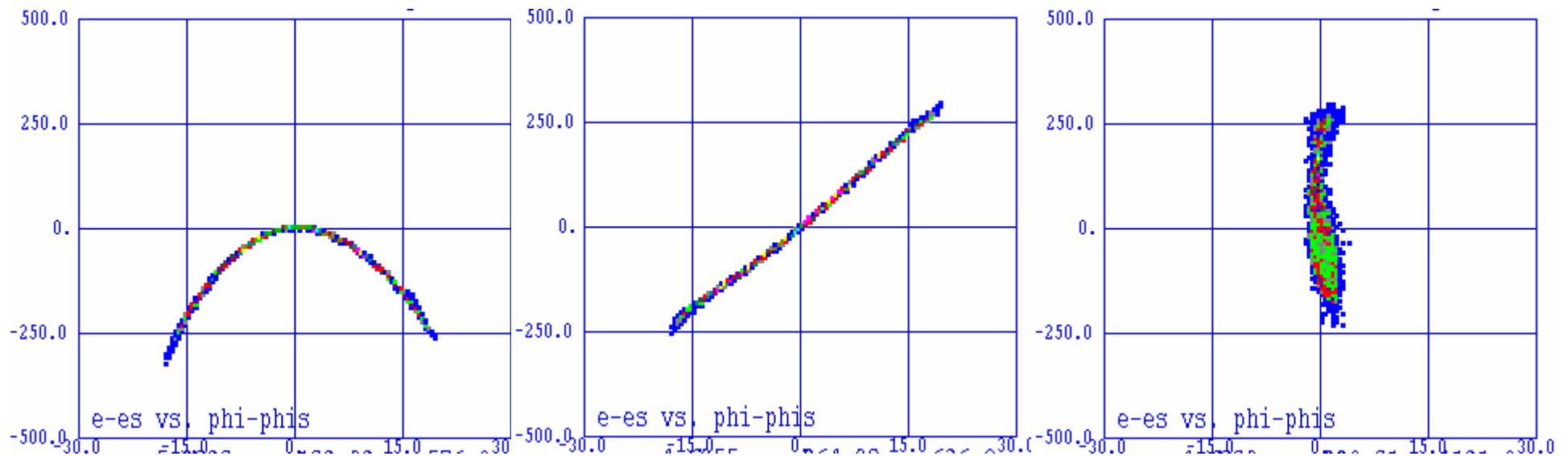50 mA CW current
~1ns pulses (5nC)
(E.Tsentalovich)

V.Litvinenko's idea

Injector design:

▪Transport of the beam from the source to the pre-accelerator ERL with minimal emittance deterioration

▪Bunch compression (to 2mm rms)

▪Spin rotation (if needed)

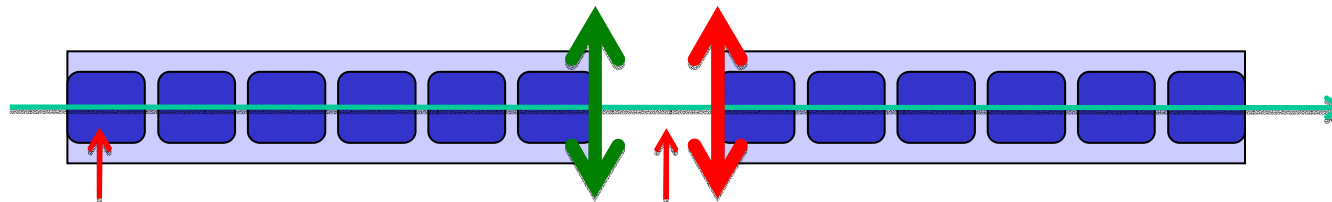# Longitudinal phase space
Beam compression process

After Booster linac   After 3rd harmonic cavity   After buncher optics

Linac Design

E.Pozdeyev

703.75 MHz
1.6 m long

Drift
1.5 m long

Constant quadrupole gradient lattice
Avoids beta-function increase with beam energy
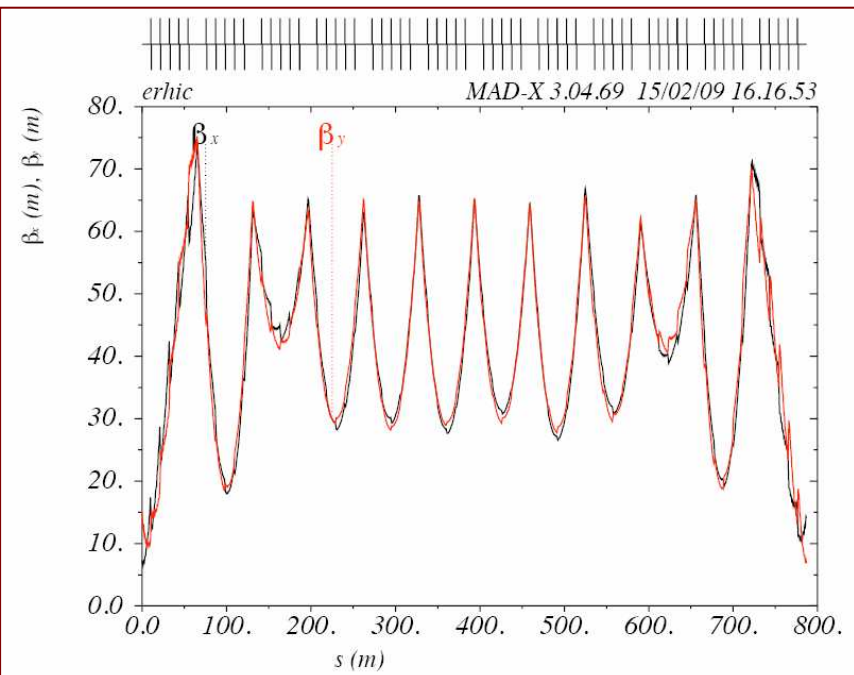Simplifies requirements for mergers/splitters

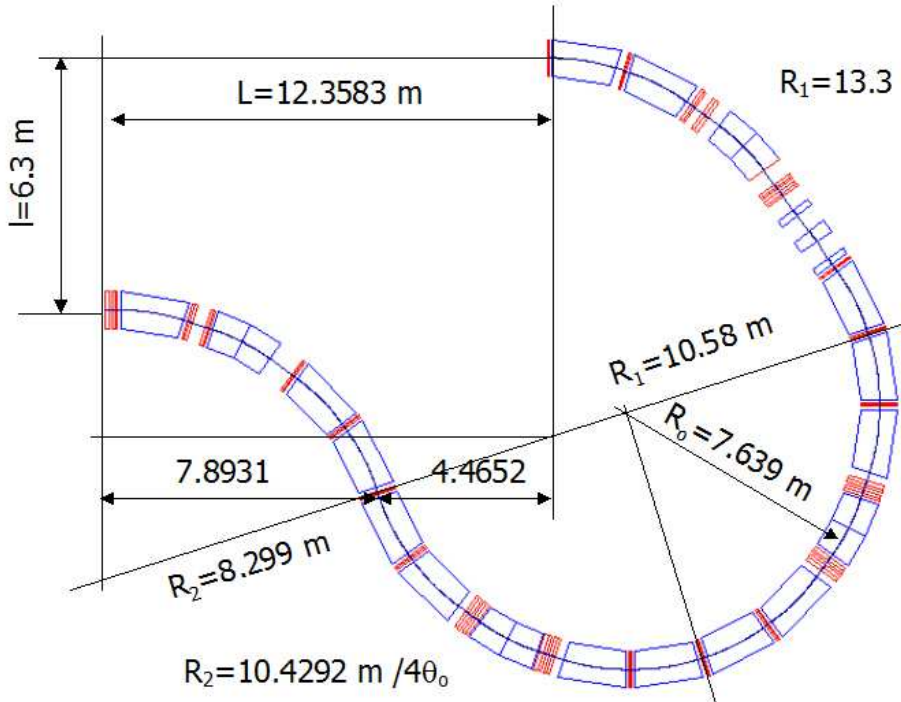65m total linac length
All cold: no warm-to-cold transition

Current breakdown of the linac

- **N cavities = 6 (per module)**
- **N modules per linac = 6**
- **N linacs = 2**
- **L module = 9.6m**
- **L period = 10.6 m**
- **E_f = 18.0 MeV/m**
- **$\langle dE/ds \rangle$ = 10.2 MeV/m**

100 MeV ⟶ 4 GeV ⟶ 100 MeV

Asynchronous arcs: 3.35 GeV
Dmitri Kayran, Dejan Trbojevic

L=12.3583 m

l=6.3 m

R_1=13.3 m/$4\theta_o$

R_1=10.58 m

R_o=7.639 m

7.8931   4.4652

R_2=8.299 m

R_2=10.4292 m /$4\theta_o$

θ_o=2π/20

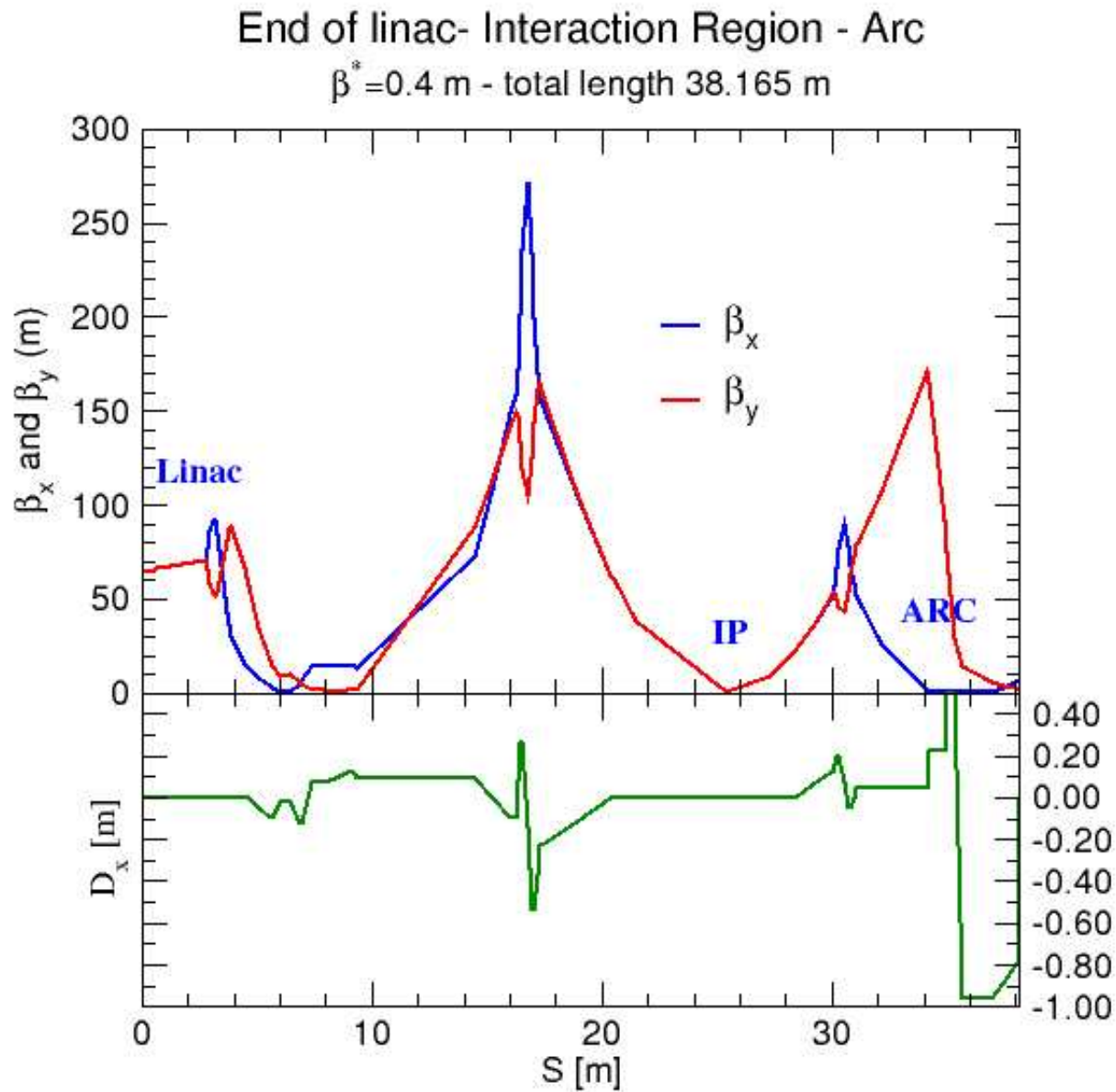Nice solution has been found for recirculation pass lattice:
- high dipole filling factor leads to the compact lattice
- M_{56} adjustments using doublets

Max dipole field 1.84 T
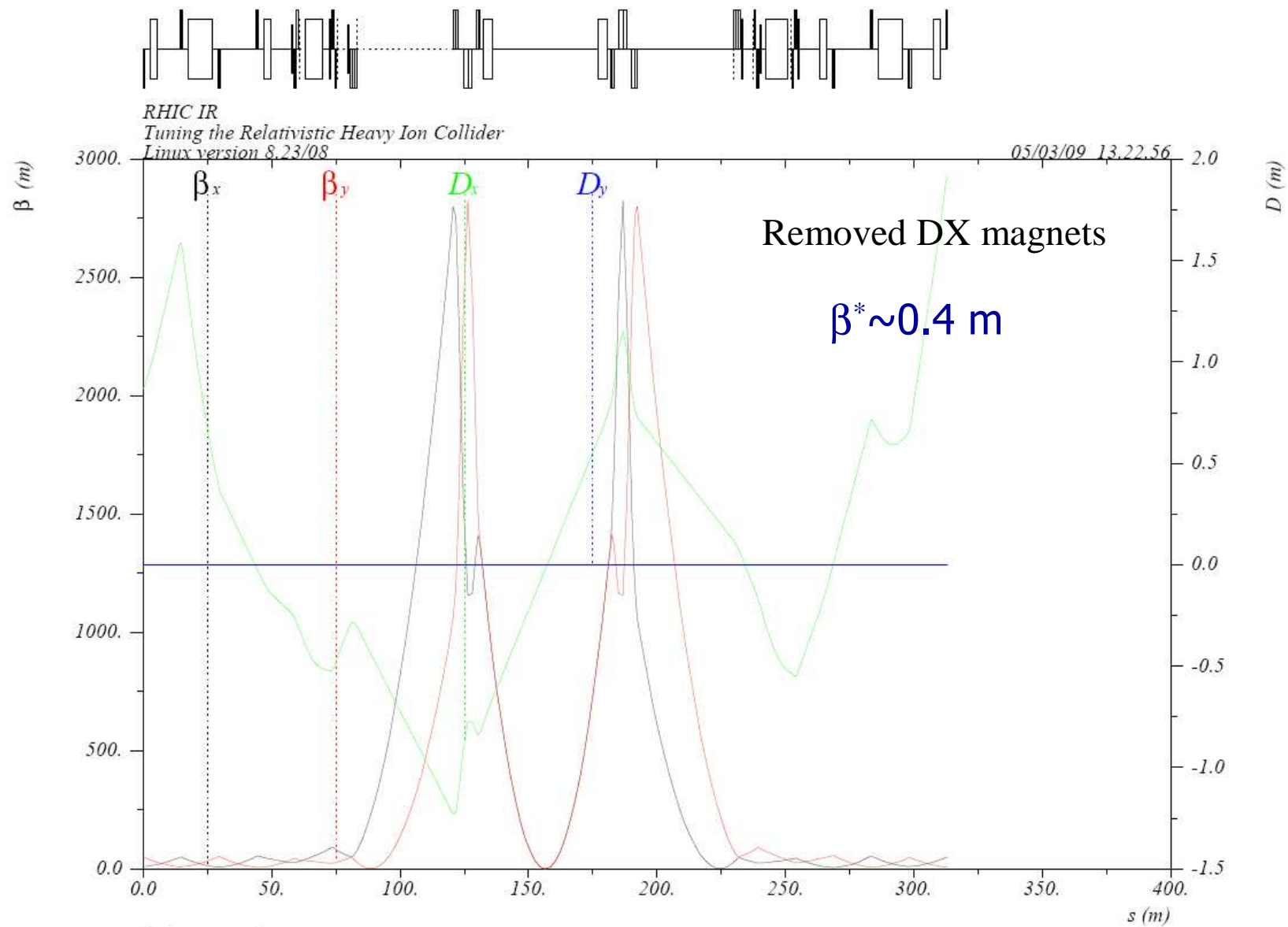
SR radiation power load <2kW/m
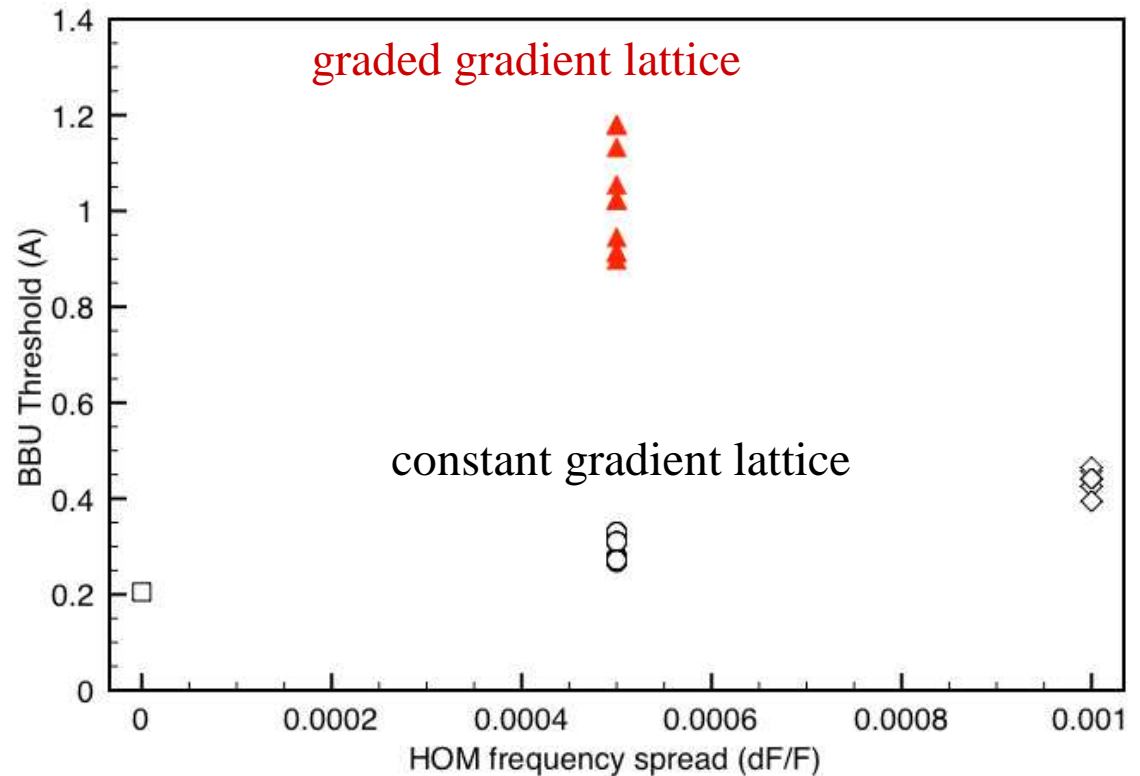
Electron IR Lattice

D.Trbojevic

End of linac- Interaction Region - Arc
$\beta^* = 0.4$ m - total length 38.165 m

RHIC lattice modification – Steven Tepikian

Removed DX magnets

$\beta^* \sim 0.4$ m

Beam Break Up simulations

- 70 dipole HOM's to 2.7 GHz
- (R/Q)×Q < 45000 Ohm
- Polarization either 0 or 90°
- 6 different random seeds
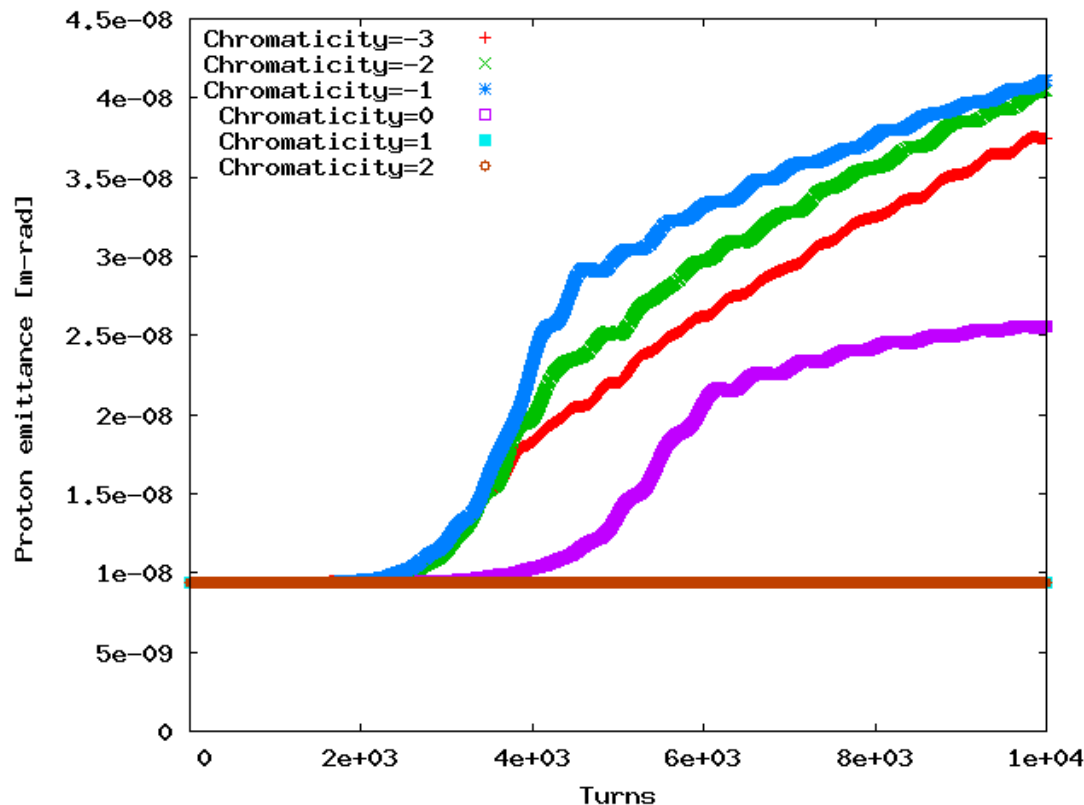- Frequency spread 0 – 1e-3

E.Pozdeyev

Beam-Beam: Kink Instability of proton beam

The beam parameters are above the threshold of kink instability for proton beam. Proper energy spread is needed to suppress the emittance growth.

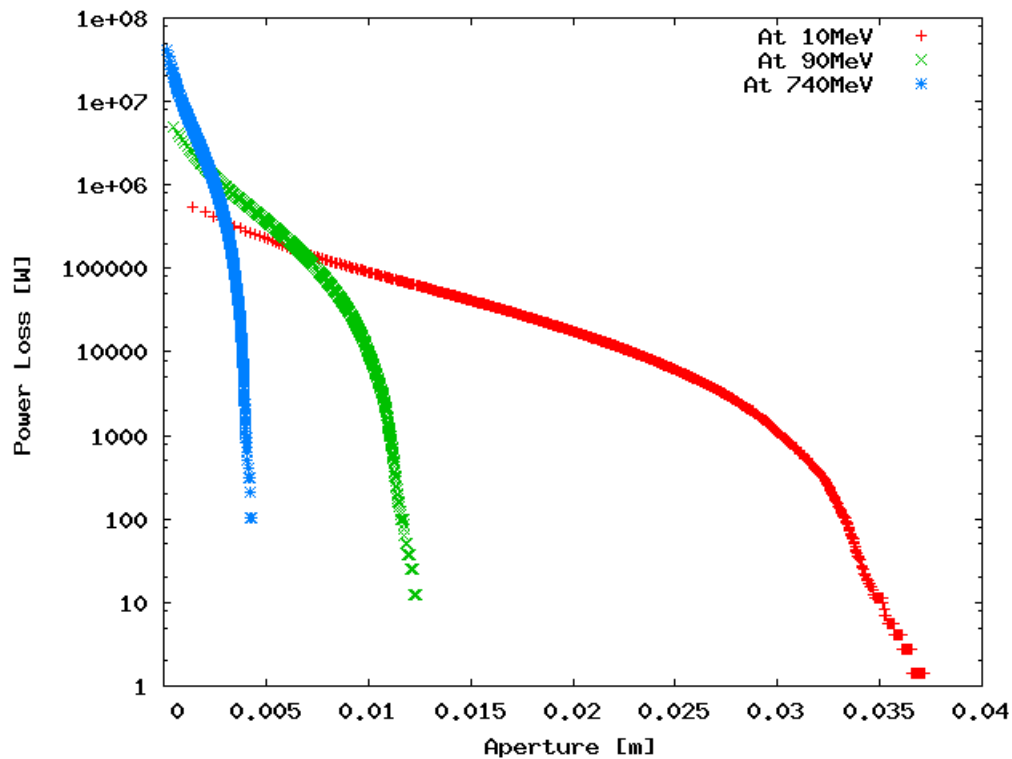From simulations of the kink instability:

Y.Hao

Not Cooled case
Chromaticity=1 is needed

Electron beam disruption

Y.Hao

Electron beam disrupted during the collisions has to be transported
and decelerated with minimal losses.

The required aperture if 1KW power
loss is required.

Energy	Aperture
740 MeV	4 mm
90MeV	11 mm
10MeV	38 mm